1. MICROWAVE RADIATION

The radiofrequency portion of the electromagnetic spectrum is subdivided into wave bands according to the schematic noted in Table 1-1. The term

Table 1-1

Wave Band Division and Designation in the Radiofrequency Spectrum

Radiofrequency Bands		
Wave Band	Frequency	Wavelength
VLF	<30 kHz	> 10 km
LF	30-300 kHz	10-1 km
MF	300-3,000 kHz	1-0.1 km
HF	3-30 MHz	100-10 m
VHF	30-300 MHz	10-1 m
UHF	300-3,000 MHz	1-0.1 m
SHF	3-30 GHz	10-1 cm
EHF	30-300 GHz	10-1 mm
Radar Frequency Bands		
Radar Band	Frequency	Wavelength
P	225-390 MHz	133.3 - 76.9 cm
L	390-1550 MHz	76.9 - 19.3 cm
S	1.55 - 5.2 GHz	19.3 - 5.77 cm
X	5.2 - 10.9 GHz	5.77 - 2.75 cm
K	10.9 - 36 GHz	2.75 - 0.834 cm
Q	36 - 46 GHz	8.34 - 6.52 mm
V	46 - 56 GHz	6.52 - 5.36 mm

microwaves will be taken to include electromagnetic energy with wavelengths in the range of 1-300 cm or wave frequencies between 30,000 and 100 megahertz (MHz). Millimeter and submillimeter waves are currently being explored for use in space communications (14, 33). Basic data on the engineering aspects of microwave hazards with methods for calculating power and energy factors are available (20, 79, 80).

Absorption and Penetration

The absorption coefficient (μ) of microwaves in tissue is defined by the exponential relationship

$$I = I_o e^{-\mu d}$$

giving the attenuation of intensity from I_o to I which a plane wave suffers as it propagates through a layer of thickness d. The inverse of μ or depth of penetration, D, is the distance covered by the radiant form of energy until its intensity is reduced to $1/e = 0.37$, its original value. In the microwave case, both μ and D are determined by the electrical and magnetic characteristics of the propagating matter. Biologic materials have no magnetic losses and their magnetic permeability is for all practical purposes identical with that of free space.

The heat (H) developed per unit volume is obtained from the derivative of this equation:

$$H = \mu I \tag{1}$$

Hence, from a knowledge of μ, it is possible to determine the distribution of heat sources. The absorption coefficient and, therefore, depth of penetration in tissue appears to be an inverse function of the wavelength and follows the equation:

$$\mu^2 = \left(\frac{2\pi}{\lambda}\right)^2 2\epsilon \left[\sqrt{1 + \left(\frac{60\lambda}{\epsilon\rho}\right)^2} - 1\right] \tag{2}$$

where (λ = wavelength in air in cm, ϵ = dielectric constant, $\rho = 1/K$ = specific resistance in Ohm-cm (60 , 61). Hence ϵ and K are found to be the essential material constants which determine the development of heat in tissue. In the case of several different layers of material the simple equations are subject to corrections which take into account that waves are in part reflected at each interface separating different tissues. The principles which determine the electrical properties of tissues and cell suspensions have been outlined and empirical data have been analyzed and well summarized (12 , 59 , 61 , 65).

The dielectric constants and specific resistances of different tissues are known and can be used to calculate penetration depths (10 , 21 , 27 , 62 , 66). The data are summarized in Table 1-2. Both dielectric constant and conductivity are temperature dependent. However, the temperature dependence of the conductance is much more pronounced than that of the dielectric constant. In the band of 50-100 MHz, the value of $100\frac{\Delta\epsilon}{\epsilon}/^\circ C$ for most tissues ranges only from -0.4 to 1.3 and the $100\frac{\Delta\rho}{\rho}/^\circ C$, from -4.9 to -1.3.

The depth of penetration of microwaves in tissue has been determined. Figure 1-3 represents the frequency dependence of penetration. Tissue with a low water content is penetrated by the radiation to a considerably larger extent than tissue with high water content such as muscle. In each case, the depth of penetration decreases rapidly with increasing frequency. For example, the wavelength of 2500 MHz provides a depth of penetration of about 9 mm in muscle. For a frequency of about 900 MHz, the depth of penetration is double that attained with 2500 MHz. The comparatively high depth of penetration in fatty tissue seems to indicate an ability of the waves to penetrate the subcutaneous fat without major energy loss and thereby to become available for heat transfer in the deep tissues. This would only be true if all the energy which reaches the muscular and other deep tissues would be absorbed by them. Partial reflection of electromagnetic waves will occur at the inter-

Table 1-2

Dielectric Constant and Specific Resistance of Body Tissues at 37°C

(After Schwan[61])

	FREQUENCY IN MHz								
	25	50	100	200	400	700	1000	3000	8500
Dielectric constant ϵ									
Muscle	103-115	85-97	71-76	56	52-54	52-53	49-52	45-48	40-42
Heart muscle				59-63	52-56	50-55			
Liver	136-138	88-93	76-79	50-56	44-51	42-51	46-47	42-43	34-38
Spleen	200	135-140	100-101						
Kidney	200	119-132	87-92	62	53-55	50-53			
Lung				35	35	34			
Skin			65		46-48		43-46	40-45	36
Brain	160	110-114	81-83						
Fat		11-13		4.5-7.5	4-7		5.3-7.5	3.9-7.2	3.5-4.5
Bone marrow		6.8-7.7					4.3-7.3	4.2-5.8	4.4-5.4
Specific resistance ρ									
Muscle		113-147		95-105	85-90	73-79	75-79	43-46	12
Heart muscle				95-115	85-100	78-95			
Liver	185-210	173-195	154-179	110-150	105-130	85-115	98-106	49-50	15-17
Spleen		128-151							
Kidney		90-145		90	85	76-77			
Lung		260-450		160	140	130			
Skin			120-140		110-130		90-110	37-50	14
Brain	220	190-210	180-195						
Fat		1700-2500		1050-3500	900-2800		670-1200	440-900	240-370
Bone marrow		2800-5000					1000-2300	445-860	210-600

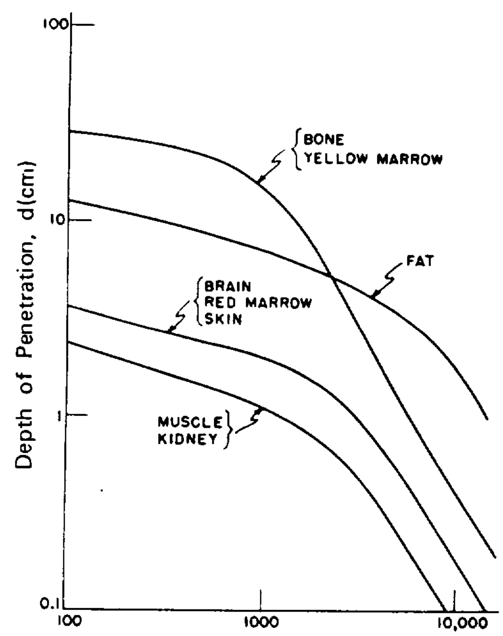


Figure 1-3

Depth of Penetration d of Typical Tissues as Function of Frequency. Average Fat Data Have Been Chosen, Not Reflecting Variability of d with Water Content.

(Adapted From Schwan [60, 67])

face separating different media. The relative amount of the total energy, which will be reflected, is determined by the dielectric constants and specific resistance values of the different media (61).

A large part of the total energy which penetrates through subcutaneous fat and reaches the muscular tissue is reflected. The reflected waves superimpose with the incident waves to form a standing wave pattern. Typical patterns of the resultant distribution of heat sources are given in Figure 1-4, for various frequencies. They illustrate the pronounced effect due to the processes of partial reflection at fat muscle boundaries.

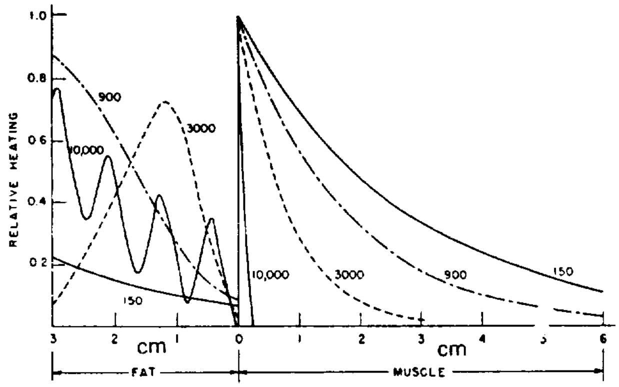


Figure 1-4

Distribution of Heat Sources in Subcutaneous Fat and Muscle. The Data Demonstrate How the Distribution of Heat Sources Changes with Frequency. All Frequencies Are Given in MHz.

(After Schwan (61))

Because of the complex reflections which would result, it appears impossible to construct a dosimeter which measures reproducibly the local absorbed energy. Biological effects must therefore be correlated with "distant field" power density measured in watts/cm^2.

The relative distribution of heat sources, as pictured in the fat-muscle complex, is not affected by the presence of the skin layer. However, at the boundary separating skin and subcutaneous fat an additional pronounced reflection results, reducing the total amount of energy delivered into the fat-muscle complex.

Thermal Factors in Microwave Absorption

The total distribution of heat sources in the skin-subcutaneous-fat-muscle complex and by summation, total heat outputs in skin, fat and muscle have been determined (62, 66). Under the simplifying assumption that the radiation strikes at a right angle to the surface of the body, Figures 1-5 and 1-6 represent absorption data for various skin thicknesses and amounts of subcutaneous fat at various frequencies. The figures illustrate that at frequencies lower than 1000 MHz, most of the energy reaches the deeply

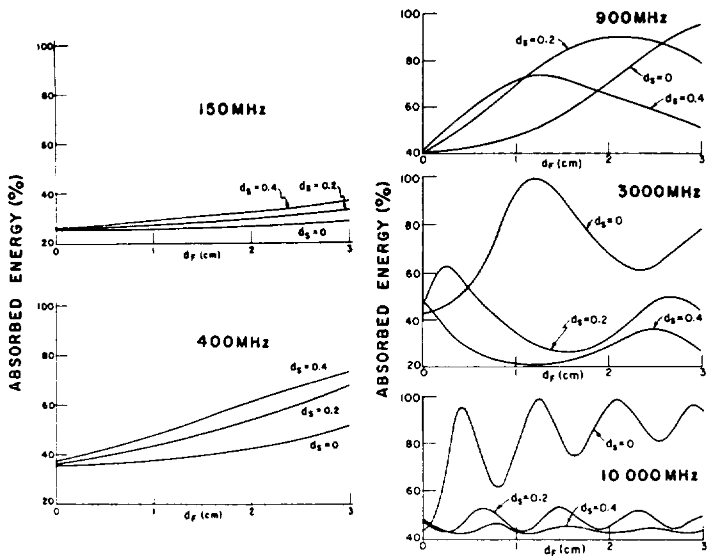


Figure 1-5

Percentage of Air-Borne Microwave Power Absorbed by the Body as a Function of Thickness d_F of Subcutaneous Fat Layer and d_S of Skin. All d Values are in cm.

(After Schwan [60])

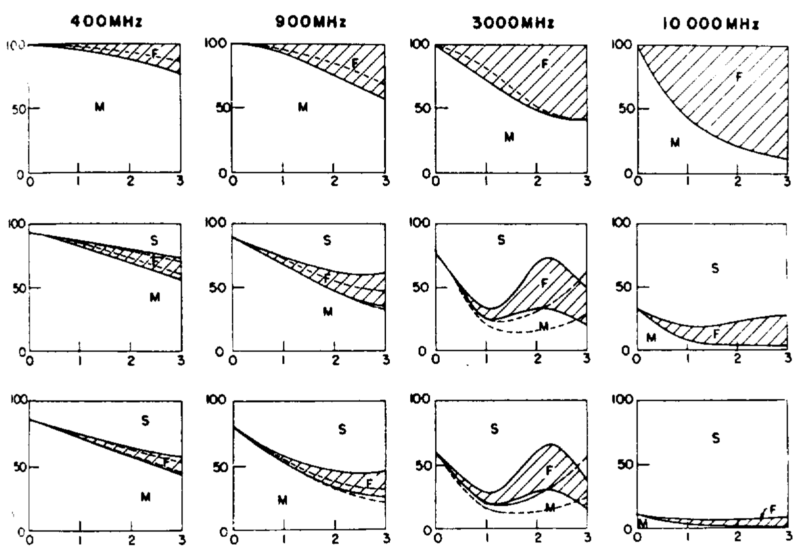


Figure 1-6

Heat Development in Skin (S), Subcutaneous Fat (F) and Deeper Situated Tissues (M) Are Given in Per Cent of Total Energy Absorbed by the Body as Function of Thickness of Subcutaneous Fat in cm. The Upper Row of Graphs Holds for a Skin Thickness K = 0, the Middle Row for K = 0.2 cm and the Lower One for K = 0.4 cm. The Solid Curves Pertain to Fat with High Water Content and the Dashed Curves to Dryer Fat. The Shaded Areas Emphasize the Heat Developed in Fat in the Wet Case. For Any Particular Combination of Values of Frequency, Thickness of Skin and Fat, the Sum of All Heat Contributions Developed in the Three Layers is 100 Per Cent in This Presentation.

(After Schwan and Li[62])

situated tissues and that for frequencies above 3000 MHz most of the radiant energy is absorbed in the skin. Between 1000 and 3000 MHz, transition from deep heating to surface heating takes place. At frequencies well below 1000 MHz and at high frequencies above 3000 MHz, the percentage of absorbed energy is nearly independent of skin and subcutaneous thickness and is about 40% of the airborne energy. In the range from 1000 to 3000 MHz, 20 to 100% of the airborne energy may be absorbed by the body depending on the thickness of skin and subcutaneous fat. The complexity of the situation prevailing in the 1000-3000 MHz band reflects the fact that in the mentioned frequency range, both skin and fatty tissue layers of the exposed body can act as a tuning element to "match" or grossly "mismatch" impedances of various tissue combinations and air.

The specific temperature attained at any depth is a function of the percent of energy absorbed, the specific weight and heat of the tissue and the heat exchange with blood and other tissue. The complexity of these interactions precludes a rigid analysis from first principles of local deep body temperatures attained under specific conditions of wavelengths, power density, and time. It is estimated from theoretical models that strong differences, which characterize the temperature elevations for various frequencies in the beginning of the application of the microwave energy, disappear in time (11). The spatial temperature distribution changes but little with time for all frequencies in excess of 3000 MHz. This reflects the fact that depth of penetration becomes so small above 3000 MHz that heat conduction rather than true penetration of radiant energy determines deep tissue temperature to a great extent. Radiation of such high frequency that heat tends to be developed at the body surface, is much less apt to cause intolerable elevation of total body temperature than radiation of lower frequencies. Presence of thermal receptors in the skin, however, increase the sensitivity of this part of the body to heat loads. Presently available knowledge makes it difficult to state how much more heat generated at the body surface is tolerable than heat generated in the deep tissues. A more differentiated dosage statement must wait, therefore, until more research has been done concerning this aspect of heat physiology.

Data are available on thermal effects of electro-magnetic fields below 100 MHz (61). These fields have been used in ultra-short wave diathermy.

Microthermal Effects

Since membranes which surround body cells have little effect on electrical properties of tissues at frequencies above 300 MHz, electromagnetic waves and fields proceed without being affected by the cell membranes (61). Hence, the cell interior and exterior are exposed to the same electric field and since their electrical characteristics are found to be fairly similar, are warmed up to nearly the same extent. As a consequence, electromagnetic waves cause rather uniform "volume" heating, not only on a macroscopic, but also on a microscopic level. This volume heating is probably due entirely to the movement of ions of the tissue electrolytes with the electrical field.

The similarity of the electrical properties of the cell interior and exterior, which is observed at ultra-high frequencies, leaves little room for specific actions of electrical fields on the individual cells, unless it is considered possible that certain molecular components respond selectively to the electrical field and that these are responsible for detectable reactions. Even more definitely can one excluue the possibility of a specific thermal effect on a microscopic level (56, 57). Such specific thermal heating is impossible even if vastly different dielectric properties of cells and surrounding medium are assumed. For the nearly identical values which hold in the frequency range of interest here, it is even more impossible. This follows from a numerical discussion incorporating dielectric data for cytoplasm and membranes of cells utilizing formulas already published (30, 64). It is still considered by some that low intensity effects of microwaves may be based on microthermal reactions (46). However, selective heating on a macroscopic level, due to differences in the electrical properties of various tissues may be anticipated as seen in Figures 1-2 and 1-3. Specific irradiation of the skull with heating of the brain may be more critical than other body sites (29, 40).

Nonthermal Effects

The possibility of nonthermal effects has been the subject of much interest. However, a review of the literature, which claims the existence of such effects, fails to be quantitatively convincing (61). This by no means excludes the possibility of nonthermal effects. More research, especially conducted from a more quantitative point of view, is needed to clarify this point. The only example of nonthermal effects which has been the subject of much detailed analysis is the tendency of microscopic particles to become rearranged under the influence of electrical fields and form chains of particles in the field direction. This pearl-chain effect was first reported in emulsions of fat particles exposed to high frequency fields (41). A more complete treatment of this and related phenomena has recently been given, but no specific biological effects can be deduced (55, 63, 70). Other nonthermal effects on proteins, enzymes, water, nervous tissue, etc., quoted in the Soviet and American literature are biologically interesting but have never been clearly shown to be related to specific symptoms and signs in man (2, 3, 5, 6, 17, 18, 23, 24, 36, 43, 50, 52, 69, 70, 74, 78).

Microwave Effects on Animals

Because of the early recognition of microwave hazards and control of exposure situations, few data are available on the accidental exposure of humans to excessive levels of microwaves.

Many animal studies with microwaves have been limited to small fur bearing creatures with high coefficients of heat absorption, small body surface, and relatively poor heat regulating systems compared to humans. The whole body of the animal is usually immersed in the beam. However, studies have been made of dogs, monkeys, and sheep. Unfortunately, the many factors which influence the response of animals, such as frequency or wavelength, time (period of exposure), irradiation cycle rate, air current, environmental temperature, position of the animal in influencing resonant conditions and standing waves, effect of reflections, difference in the sensitivity of organs and tissues, use of anesthesia or tranquilizer drugs, and, last but not least, the type of animal, make comparisons very difficult. The effects can be summarized as total body, ocular, and testicular.

Total Body Effects

The magnitude of the rise in body temperature depends upon the degree of imbalance between heat production and heat loss. If the rise of temperature is excessive, the damage produced is indistinguishable from that due to fever of any origin. (See Thermal Environment, No. 6). During the rise in temperature, reactions indicative of a nonspecific pituitary-adrenal response to stress occur, including a sharp decrease in eosinophils and lymphocytes, and a rise in leukocytes (19, 29, 37, 42, 43, 45, 69). Severe hyperpyrexia carried to the point of death results in diffuse degenerative lesions throughout the body, including renal tubular degeneration, myocardial degeneration and necrosis, hemorrhagic lesions in the gut, respiratory tract, liver, and brain. Fatally exposed animals develop acidosis, hyperpnea, and tetany, and finally die of respiratory arrest (31). (See Figure 1-7).

Nervous System

Exposure of animals to microwaves of low intensity, which do not produce any appreciable thermal effect ($<10 mW/cm^2$) lead to functional changes according to some Russian workers (15, 23, 25, 35, 36, 46). Such changes take place mainly in the nervous and cardiovascular systems (change in excitation and inhibition relationships in cerebral cortex, change in rhythm of cardiac activity, etc.). Possible neuro-endocrine response such as increased thyroid activity has also been found in dogs (43). These changes were observed both with chronic and with single exposures and have been termed as nonthermal, specific effects of microwaves (23). The varied effects of microwaves on animal behavior have been recently reviewed (75).

Eye

Localized microwave radiation at certain frequencies, either continuous or pulsed, causes a rise in intraocular temperature and the formation of opacities in the lens (5, 9, 19, 34, 53, 61, 68, 82, 83). Over the several wavelengths studied, from 400-3000 MHz, the threshold for damage after exposure of more than about 20 minutes was in the range of 100-200 mW/cm^2. For less than about 20 minutes, the damage threshold increases.(See Figure 1-7). In the frequency range of 5400 to 5500 MHz, a power density of about 800 mW/cm^2 for 20 minutes causes lenticular changes in the eyes of 50 percent of exposed rabbits (83). At subthreshold power levels, there is still some question regarding the cumulative effects on the lens (5, 68). Differences in patterns of peak pulse levels and off time between pulses may be critical factors.

Testis

The characteristic lesion found in the testis is a degeneration of the epithelium lining the seminiferous tubules, and a sharp reduction in the number of maturing spermatocytes in the lumen. There is patchy irregular distribution of damage within the testis, adjacent tubules often showing markedly different degrees of degeneration. The damage is almost certainly reversible except in severe cases (19, 31). A very conservative threshold for testicular damage in the dog exposed to 3000 MHz microwaves under tranquilizer sedation for several hours is around 5mW/cm^2 (19).

Figure 1-7 summarizes threshold curves in the dog for 3000 MHz microwaves of relatively high absorptivity. These curves separate dose rate levels which do no damage from those which are dangerous. For prolonged exposure, these threshold levels are independent of exposure time, while for short exposure, the response is a function of dose and time making it dose-rate dependent. Different curves pertain to the three specific effects because different levels of critical temperature elevation must be considered. For example, for continuous exposure, cataracts result if the eye temperature reaches at least 45^{o}C, but much lower temperature elevations in excess of 1^{o}C are considered intolerable from the point of view of testicular damage, even though not necessarily fatal. These represent animal data most pertinent to man.

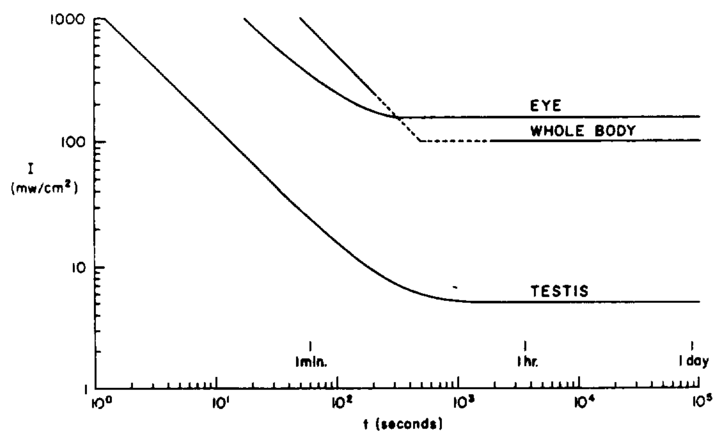


Figure 1-7

Threshold Field Intensities as a Function of Time of Exposure to 3000 MHz Microwaves (10 cm) for Three Sensitive Structures in the Dog.

(After Ely and Goldman (19))

Microwave Effects in Humans

Knowledge regarding human exposures to radar has been on a retrospective basis. In the U. S. A., a large group of radar-exposed employees, along with a control group, were put under a four-year surveillance program (4). During this period, they underwent repeated physical and eye examinations.

Detailed hematological and other laboratory investigations were carried out. The examinations failed to detect any significant changes in the physical inventories of the subjects. The incidence of death and chronic disease, sick leave and subject complaints was comparable in both groups. A high percentage of eye pathology was identified, but none with causal relation to the hyperthermia produced by microwave absorption. Fertility studies revealed essentially the same findings for both groups. Laboratory studies and chest x-rays were noncontributory with respect to radar exposures.

Only a small percentage of the exposed subjects had been aware of the heat or other subjective warning phenomena (4). Neither these tests nor subjective complaints are considered reliable indices of exposure. The sensation of heat or vibration may accompany overexposure to radar in some cases (4). Only 17% of subjects experienced a heat sensation when in close proximity to "X" band radar; 6% were aware of buzzing or pulsating sensation when in an "S" band field. Less than 1% experienced other sensations, such as sparking between dental fillings and metallic tastes. The buzzing sensations which tend to peak at the 600-1500 MHz region have received recent study (7, 22). Occasionally, epigastric distress and/or nausea may occur at power densities as low as 5-10 mW/cm^2, and are most commonly associated within the frequency range from 8×10^3 to 12×10^3 MHz (80). A feeling of warmth may be experienced when the heating effect occurs mainly on the skin. This phenomenon is most commonly associated within the frequency range from 8×10^3 to 26×10^3 MHz (80).

An eye survey of a large group of microwave workers - both civil and military - has been concluded (85). Barring an occasional case of cataract in workers accidentally exposed to high microwave flux, the overall eye findings in workers and an equally large control group were clinically insignificant. The extent of minor lenticular imperfection does not serve as a clinically useful indicator of cumulative exposure to microwave radiation. No relationship between lens imperfection and microwave cataract was found. In other surveys and reports of isolated cases, quantitation of power densities was inadequate to set a definite microwave threshold for cataract formation in humans (8, 28). Recently, 26 cases of lenticular changes were found in microwave workers having a high probability of exposure to more than 10 mW/cm^2. One of these cases has progressed to cataract and loss of vision (84). These new cases suggest to the investigator that "the threshold for human cataractogenesis may approximate 100 Mev/cm^2 instead of the previously accepted state-of-the-art value lying between 350 and 500 mW/cm^2," but no statistical evidence is presented. In the Soviet Union, several cataract surveys have been reported (17, 38, 71). Some cataracts having a tendency to progress have been observed among microwave workers but no threshold data are available (17).

Many poorly defined symptoms have been attributed to microwaves. The Soviet observers have conducted a series of examinations on their radar workers and control groups (15, 16, 17, 18, 32, 35, 46). Unfortunately, quantification of exposure levels has been poorly defined. Chronic irradiation under industrial conditions produces extremely polymorphic changes in the state of the human organism, causing functional changes in various organs and systems. The degree of their manifestation and the presence of characteristic symptoms are determined by the intensity and duration of the microwave influence as well as by peculiarities of the exposed individual. The clinical syndrome is basically characterized by the presence of asthenia and vegetative reactions. The asthenic reactions such as headache, increased fatigability, increased irritability and sleepiness are not usually sharply pronounced, and have no distinguishing features. Similar observations have been made in a number of laboratories in the U.S.A. and United Kingdom (69). Cardiovascular changes such as arterial hypotension and hypertension (39), bradycardia, sinus arrhythmia, lengthening of the conduction time in the heart, reduction of the amplitude of the spikes of ECG are noted. The asthenic and vegetative reactions mentioned above are entirely reversible. Intensification of the activity of thyroid tissue was detected in almost all the workers investigated by one Soviet author (17). In some surveys, a small increase in volume of the thyroid gland was noted; however, in all surveys, clinical symptoms of hyperfunction were detected only in isolated cases (17, 35, 72). Exposure of Soviet medical personnel to 170-1000 mW/cm^2 of 1.6 to 2450 MHz diathermy devices has led to symptoms such as headache, irritability, insomnia, chest pain, hand tremor, etc. (73). The significance of these Soviet findings above and below 10 mW/cm^2 is not clear and their use in establishment of threshold or allowable microwave exposure levels is open to serious question. There is a lack of information on the measurement of actual exposure levels.

Data are available pertaining to irradiation of restricted parts of the human body as performed, for example, in clinical practice (11, 26). At a frequency of 2500 MHz and power input of 100 watts over an area of 100 cm^2, the initial rapid temperature rise of about 1°C per minute lasts only for a few minutes in the deep tissues under this area. In vascular tissues such as muscle, the temperature peak occurs at about 20 minutes and then decreases again to a value between initial body temperature and peak temperature, reflecting the effect of more efficient cooling of the irradiated segment due to vasodilatation.

Human Tolerance Limits for Microwaves

Determination from first principles of power density limits for continuous exposure has been difficult. Current approaches in the U.S.A. take into consideration only the thermal factors. For continued or interrupted exposure of the body beyond several minutes duration, one can estimate an approximate limit of power density when only the gross volume heating effect is considered (62, 66). The steady-state temperature elevation depends on the ratio of irradiated part of the body surface to total body surface and will increase with the area of irradiation. This means that a power density of about 0.3 watts/cm^2 must result in a temperature rise of more than 1°C if the area irradiated beyond several minutes is larger than 100 cm^2. If linearity is assumed between tolerance flux figure and ratio of nonirradiated to irradiated body surface, a figure of 0.03 watts/cm^2 may be found dangerous if at least half of the body (i.e., about 1 m^2) is exposed. Average heat dissipation under normal circumstances is about 0.005 watts/cm^2. This figure is based on an energy uptake in form of food of 3000 Kcal per day, an efficiency of somewhat below 30 percent and a body surface of about 2 m^2. Only under unusually fortunate circumstances is the body surface able to handle tenfold higher heat flux figures. However, double the above rate seems well within the capacity of the human body. This means that it is permissible to develop inside the human body an additional amount of energy which corresponds to 0.005 watt/cm^2, averaged over the total body surface. In view of the fact that the shadowing factor limits exposure to half of the body surface, a figure of 0.01 watt/cm^2 absorbed energy appears as tolerable and is, therefore, suggested as a tolerance dosage (62, 66). This value should not be exceeded except under unusual circumstances, where cooling efficiency of body surface is excellent.

One must also consider short time exposure to very high intensities where heat flow is not very effective, i.e., whenever time of exposure is small compared with the time constants which characterize heat exchange in the human body. If temperature elevation of more than 1°C is considered intolerable in the case of total body irradiation, 0.3 watt minutes/cm^2 can be calculated as the limiting value. Since depth of penetration of radiation decreases with increasing frequency, this figure should be replaced by higher values at frequencies below 1000 MHz and by lower values above 3000 MHz, the adjustment for heating of the skin makes the exact nature of this adjustment quite uncertain.

If 0.01 watt/cm^2 for long time exposure and 0.1 watt hour/cm^2 for short exposures are not to be exceeded in case of total body exposure, the following tolerance levels for specific frequency ranges can be deduced:

> For microwave frequencies below 500 MHz with a coefficient of absorption of about 30 to 40 percent, true deep heating is possible. An incident energy flux of less than 0.03 watt/cm^2 can probably be tolerated.
>
> For frequencies from 1000 to 3000 MHz with possibly complete absorption by skin, subcutaneous fat, and deep tissues, 0.01 watt/cm^2 may be considered tolerable.
>
> For frequencies in excess of 3000 MHz which are absorbed in the surface of the body with a coefficient of absorption of airborne energy of 40 to 50 percent and excellent heat dissipation from surface structures, a power density level of 0.2 watt/cm^2 should be tolerable but this is the least certain of these predictions.

The above analysis assumes that heat development occurs more or less uniformly through the total medium (volume heating). However, local heating at a subcellular level may present specific heating effects in the degradation of cellular function. There is as yet no specific evidence for such a local thermal effect (61). The above analysis also reflects tolerance limited by heating of the skin and peak power factors from pulsed microwaves.

In view of the above analysis, and the data of Figure 1-7, the most common power density standard for maximum continuous total body exposure of humans to any wavelength has been 10 mW/cm^2 (66). More recent evaluation by the U.S.A. Standards Institute has resulted in a proposed standard for exposure of any time duration as (81): "For normal environmental conditions and for electromagnetic radiation of frequencies from 10 to 100,000 MHz the radiation protection guide is 1 mW hr/cm^2 in any 0.1 hour period. This means: (a) 10 mW/cm^2 for periods of 0.1 hour or more or (b) 1 mW hr/cm^2 for periods up to 0.1 hour. In the case of pulsed fields, the radiation should be averaged over complete trains of pulses, including intervals between pulse trains."

The recent USAF extrapolation of these standards reads (80):

> Exposure of personnel within limited occupancy area is permitted only for the length of time given by the following equation:

$$Tp = \frac{6000}{W^2}$$

Where: Tp = permissible time of exposure in minutes during any 1-hour period.

W = power density in area to be occupied in mW/cm^2.

The above equation is applicable only to power densities between 10 mW/cm^2 and 100 mW/cm^2. (See Figure 1-8 for graphic presentation). It is not feasible to control limited exposures of less than 2 minutes and consequently this formula should not be applied to intensities over 55 mW/cm^2.

The U. S. Navy Standards adds to the 10 mW/cm^2 level the fact that incident energy level should not exceed 300 millijoules per sq. cm. per 30 second interval (7).

Calculation of power density levels at any point in a radar beam should follow USAF recommendations (79, 80). An adequate estimate of safe exposure below 10 mW/cm^2 with stated limitations can be obtained from Table 1-9 (49).

The differences between these various recommendations are relatively minor and have as yet not been unified by any single government standard. In emergency situations where the above limits must be exceeded for emergency operations, it is suggested that an anti-microwave suit be used (54). Reduction of body temperature by exposure to a cold environment will also decrease thermal hazards of exposure.

The Soviet limits of safe exposure are more than one order of magnitude less than the U.S. levels.

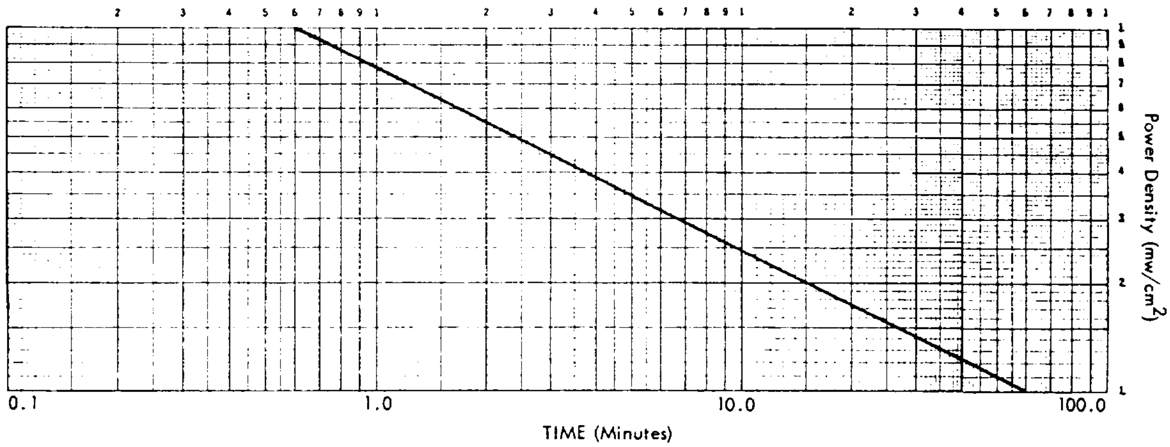


Figure 1-8

Permissible Exposure Time

$$T_p = \frac{6000}{W^2}$$

EXAMPLE:
KNOWN: Power density = W = 25 mw/cm^2

$$T_p = \frac{6000}{(25)^2} = \frac{6000}{625} = 9.6 \text{ min}$$

(After AFM 161-7 [80])

Permissible exposure time may be obtained by use of figure.
Known power density = 25 mw/cm^2.
Enter figure on vertical axis at 25 mw/cm^2.
Follow horizontal entry line to intersection of curve.
Project vertical line from intersection to horizontal axis.
Read approximately 9.6 minutes.

Table 1-9
Safe Distance Formulas

If Average Power in Watts (W) Is:	Safe Distance in Feet Is:
Less than $3D^2$	SAFE
Between $3D^2$ and $5.8D^2$	$\frac{2.85\ W}{\text{Wave length in cm.}}$
Over $5.8D^2$	$\frac{6.85\ D\sqrt{W}}{\text{Wave length in cm.}}$
Chart applies to pencil-beam radar with parabolic or microwave lens antenna of diameter D feet. Safe distances based on power density of .010 watt/cm^2.	

(After Overman [49])

- In the case of irradiation during the entire working day - no more than 0.01 mW/cm^2.
- In the case of irradiation for no more than two hours per working day - no more than 0.1 mW/cm^2.
- In the case of irradiation for no more than 15 to 20 minutes per working day - no more than 1.0 mW/cm^2. (In this case, the use of protective goggles is mandatory).

No adequate data supporting such low levels are available (47). The vague "asthenia" syndromes reported above may have been a factor (16, 17, 18, 35, 46) as were the nonthermal neural effects seen in animal studies (15).

No formal limits have been set for electromagnetic fields below 10 MHz (61). No limits have been suggested for unusual situations where strong magnetic fields are present with weak electric fields and vice versa.

Microwave Cross-Section of Man

The microwave cross-section of man is a microwave parameter which may be of value in such operations as search and rescue. Unfortunately, there are no data available on man in a pressure suit, especially an aluminized suit. Data are available on the monostatic and bistatic radar cross sections of a 200 lb man at 410, 1120, 2890, 4800, and 9375 MHz (58). The measurements were made with a cw Doppler technique using both horizontal and vertical polarizations and for various facing aspects. Figures 1-10 to 1-14 present the data from several points of view.

The cross sections vary from 0.33 to 2.33 square meters, with the extremes at 410 mc; the smaller for horizontal polarization at side view and the larger for vertical polarization at rear view. The cross section is least for side view, and somewhat greater for rear than front view. As expected, there is a general decrease in polarization dependence as the frequency is increased. The microwave cross section is approximately proportional to the weight of man. The theory of microwave cross sections in biological systems is available (1).

Microwaves and Ionizing Radiation

The generation of microwaves at high power levels causes production of pulsed X-rays (13). Magnetrons, klystrons, and traveling wave tubes are the primary source of the radiation. It is recommended that shielding of these sources and operational procedures be instituted to keep human exposure to levels below those recommended in the Ionizing Radiation, (No. 3).

Subtle changes resulting from microwave exposure have been shown to alter the response of animals to ionizing radiation. Prior exposure to 2800 MHz microwaves increased the LD_{50} for X-rays in several species of animals (44, 51, 76, 77) and decreased specific symptoms and lethality in dogs after x-irradiation of the head (44). Simultaneous exposure decreased resistance to the x-irradiation. The specific effects of frequency, microwave, and X-ray doses and dose rates, and temporal separation of the two radiation modes have not yet been adequately determined, nor has the significance of this synergism been established for human exposure.

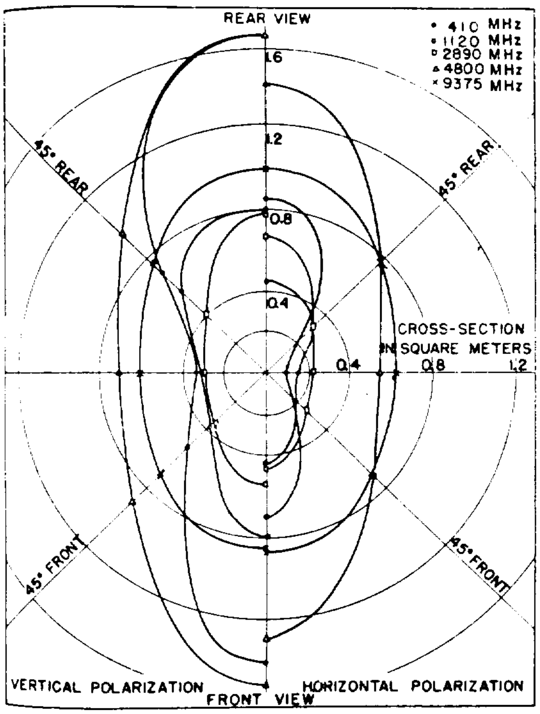


Figure 1-10

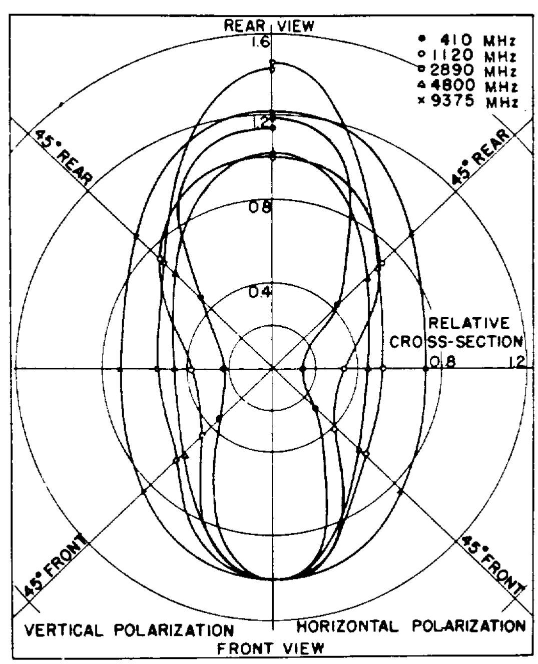
Average Bistatic Radar Cross Section of a Man as a Function of Target Aspect Angle, with Frequency and Polarization as Parameters.

(After Schultz et al [58])

Figure 1-11

Average Relative Bistatic Radar Cross Section of a Man as a Function of Target Aspect Angle, with Frequency and Polarization as Parameters.
(The Curves Are Normalized with Respect to the Radar Cross Section of the Front Aspect.)

(After Schultz et al [58])



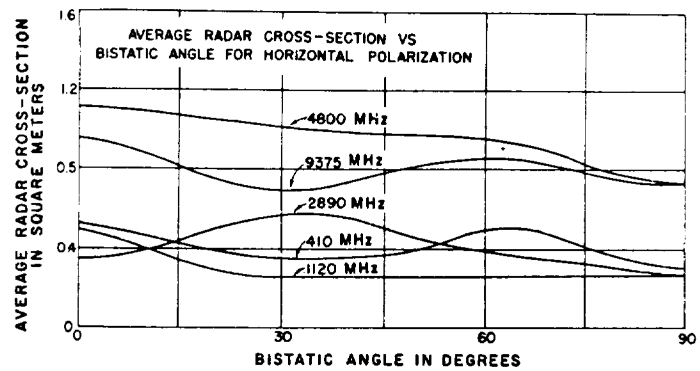


Figure 1-12

Average Bistatic Radar Cross Section of a Man as a Function of Bistatic Angle, for Horizontal Polarization with Frequency as a Parameter.

(After Schultz et al [58])

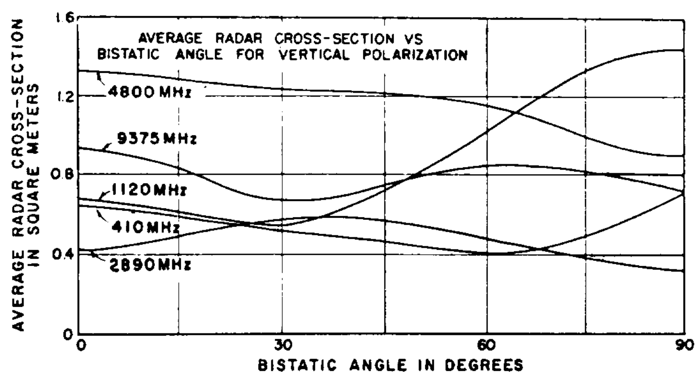


Figure 1-13

Average Bistatic Radar Cross Section of a Man as a Function of Bistatic Angle for Vertical Polarization with Frequency as a Parameter.

(After Schultz et al [58])

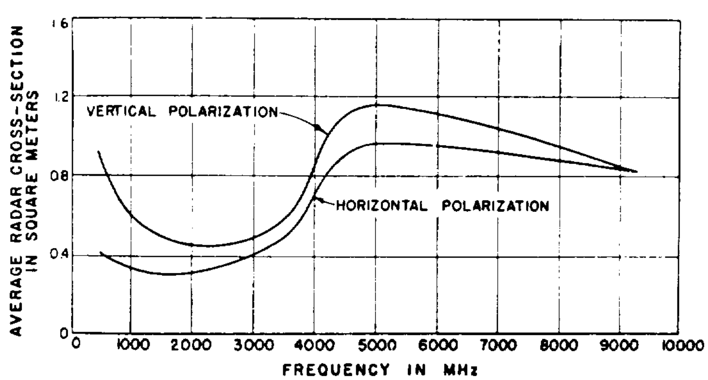


Figure 1-14

Average Radar Cross Section of a Man as a Function of Frequency with Polarization as a Parameter.

(After Schultz et al [58])

REFERENCES

1-1. Anne, A., Saito, M., Salati, O. M., et al., Relative Microwave Absorption Cross Sections of Biological Significance, in Peyton, M. F., Biological Effects of Microwave Radiation, Proceedings of the Fourth Annual Tri-Service Conference, Vol. 1, Plenum Press, New York: 1961, pp. 153-176.

1-2. Bach, S. A., Biological Sensitivity to Radio-Frequency and Microwave Energy, Fed. Proc., 24: S22-S26, 1965.

1-3. Bach, S. A., Luzzio, A. J., Brownell, A. S., Effects of Radio-Frequency Energy on Human Gamma Globulin, Peyton, M. F. (ed.), Biological Effects of Microwave Radiation, Proceedings of the Fourth Annual Tri-Service Conference, Vol. 1, Plenum Press, New York: 1961, pp. 117-133.

1-4. Barron, C. I., Baraff, A. A., Medical Considerations of Exposure to Microwaves (Radar), JAMA, 168 (9): 1194-1199, 1958.

1-5. Carpenter, R. L., An Experimental Study of the Biological Effects of Microwave Radiation in Relation to the Eye, RADC-TDR-62-131, Rome Air Development Center, Griffiss AFB, N. Y., Feb. 1962 (AD-275840).

1-6. Carr, P. H., Harmonic Generation of Microwave Phonons by Radiation Pressure and by the Phonon Phonon Interaction, AFCRL-66-802, Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Mass., Dec. 1966.

1-7. Christianson, C., Rutkowski, A., Electromagnetic Radiation Hazards in the Navy, NASL-TM-5, U. S. Naval Applied Science Laboratory, Brooklyn, N. Y., 1967.

1-8. Cleary, S. F., Pasternack, B. S., Lenticular Changes in Microwave Workers, Arch. Environ. Health, 12: 23-29, 1966.

1-9. Cogan, D. G., Fricker, S. J., Lubin, M., et al., Cataracts and Ultra-High-Frequency Radiation, A.M.A. Arch. Indust. Health, 18: 299-302, 1958.

1-10. Cook, H. F., The Dielectric Behavior of Some Types of Human Tissues at Microwave Frequencies, Brit. J. Appl. Phys., 2: 295-300, 1951.

1-11. Cook, H. F., A Physical Investigation of Heat Production in Human Tissues When Exposed to Microwaves, Brit. J. Appl. Phys., 3: 1, 1952.

1-12. Debye, P. F. W., Polar Molecules, Chemical Catalog Co., Inc., New York, 1929.

1-13. DeMinco, A. P., Generation and Detection of Pulsed X-Rays from Microwave Sources, in Peyton, M. F., Biological Effects of Microwave Radiation, Proceedings of the Fourth Annual Tri-Service Conference, Vol. 1, Plenum Press, New York: 1961, pp. 33-46.

1-14. Derr, V. E., Propagation of Millimeter and Submillimeter Waves, NASA-CR-863, Aug. 1967.

1-15. Dodge, C., Soviet Research on the Neural Effects of Microwaves, LC-ATD-66.-133, Library of Congress, Aerospace Technology Division, Washington, D. C., Nov. 1966. (AD-645979)

1-16. Drogichina, E. A., Konchalovskaya, N. M., Glotova, K. V., et al, Autonomic and Cardio-vascular Disorders During Chronic Exposure to Super-High Frequency Electromagnetic Fields, LC-ATD-66-124, Library of Congress, Aerospace Technology Division, Washington, D. C. (Translation of Gigiyena Truda i Professional'nyye Zabolevaniya, 10(7): 13-17, 1966).

1-17. Drogichina, E. A., The Clinic of Chronic UHF Influence on the Human Organism, in Letavet, A. A., Gordon, Z. V., The Biological Action of Ultrahigh Frequencies, JPRS-12471, Joint Publications Research Service, Washington, D. C., Feb. 15, 1962. (Translation of O Biologicheskom Vozdeistvii Sverkhyysokokh Chastot, Moscow, Acad. of Med. Sci., USSR, 1960, pp. 22-24.)

1-18. Drogichina, E. A., Sadchikova, M. N., Clinical Syndromes Arising Under the Effect of Various Radio Frequency Bands, JPRS-29694, Joint Publications Research Service, Washington, D. C., April 1965. (Translation of Gigiyena Truda i Professional'nyye Zaboleveniya, 9(1): 17-21, Jan. 1965).

1-19. Ely, T. S., Goldman, D. E., Heating Characteristics of Laboratory Animals Exposed to Ten-Centimeter Microwaves, NMRI-NM-001-056.13-02, Naval Medical Research Institute, Bethesda, Md., Mar. 1957.

1-20. Engelbrecht, R. S., Mumford, W. W., Some Engineering Aspects of Microwave Radiation Hazards, in Peyton, M. F., (ed.), Biological Effects of Microwave Radiation, Proceedings of the Fourth Annual Tri-Service Conference, Vol. I, Plenum Press, N. Y., 1961, pp. 55-70.

1-21. England, T. S., Dielectric Properties of the Human Body for Wave-Lengths in the 1-10 cm. Range, Nature, 166: 480-481, 1950.

1-22. Frey, A. H., Some Effects on Human Subjects of Ultra-High Frequency Radiation, Amer. J. Med. Electronics, 2(1):28-31, 1963.

1-23. Gordon, Z. V., The Problem of the Biological Action of UHF, in Letavet, A. A., Gordon, Z. V. (eds.), The Biological Action of Ultrahigh Frequencies, JPRS-12471, Joint Publications Research Service, Washington, D. C., Feb. 15, 1962. (Translation of O Biologicheskom Vosdeystvii Sverkhyysokikh Chastot, Moscow, Acad. of Med. Sci., USSR, 1960, pp. 5-7.)

1-24. Gordon, Z. V., Problems of Industrial Hygiene and of the Biological Effect Produced by Radio-Waves of Different Bands, JPRS-27032, Joint Publications Research Service, Washington, D. C., October 1964, pp. 61-71. (Translation of Vestnik Academic Meditsinski Nauk SSSR, 19(7): 42-49, 1964).

1-25. Gvozdikova, G. M., Anan'yev, V. M., Zenina, I. N., et al., Sensitivity of the Rabbit Central Nervous System to a Continuous Ultra-High Frequency Electromagnetic Field, in Recent Works on "Skin Vision", The Central Nervous System and Radiation Sickness, JPRS-26725, Joint Publications Research Center, Washington, D. C., Oct. 1964, pp. 31-37. (Translation of article in Bull. Exp. Biol. Med., Moscow, 29(8):63-68, 1964).

1-26. Herrick, J. F., Krusen, F. H., Certain Physiologic and Pathologic Effects of Microwaves, Elec. Engrg., 72: 239, 1953.

1-27. Herrick, J. F., Jelatis, D. G., Lee, G. H., Dielectric Properties of Tissues Important in Microwave Diathermy, Fed. Proc., 9: 60, 1950.

1-28. Hirsch, F. G., Parker, J. T., Bilateral Lenticular Opacities Occurring in a Technician Operating a Microwave Generator, A.M.A. Arch. Ind. Hyg. and Occup. Med., 6: 512-517, 1952.

1-29. Howland, J. W., Thomson, R.A.E., Michaelson, S. M., Biomedical Aspects of Microwave Irradiation of Mammals, Peyton, M. F. (ed.), Biological Effects of Microwave Radiation, Proceedings of the Fourth Annual Tri-Service Conference, Vol. I, Plenum Press, New York: 1961, pp. 261-284.

1-30. Hug, O., Pape, R., Nachweis der Ultraschallkavitation im Gewebe, Strahlentherapie, 94: 79-99, 1954.

1-31. Kalant, H., Physiologic Hazards of Microwave Radiation: A Survey of Published Literature, Canod Med. Assn. J., 81: 575-582, 1959.

1-32. Klimkova-Deutscheova, E., Effect of Radiation on Human EEG, FTD-TT-64-267/2, Foreign Technology Division, Wright-Patterson AFB, Ohio, 1964. (Translation of Ceskoslovenska Neurologie, 26(3): 1963, pp. 22-23). (AD-450604).

1-33. Kulke, B., Millimeter-Wave Generation with Electron-Beam Devices, NASA-TN-D-3727, Feb. 1967.

1-34. Lerman, S., Radiation Cataractogenesis, N. Y. State J. Med., 62(19): 3075-3084, Oct. 1962.

1-35. Library of Congress, Biological Effects of Microwaves, Compilation of Abstracts, LC-ATD-P-65-68, Aerospace Technology Division, Washington, D. C., Sept. 1965.

1-36. Livshits, N. N., The Role of the Nervous System in Reactions to UHF Electromagnetic Fields, Biophysics, 2(3): 372-384, 1957.

1-37. McLaughlin, J. T., Health Hazards from Microwave Radiation, Western Med., 3: 126-132, Apr. 1962.

1-38. Minecki, L., Bilski, R., The Health of Persons Exposed to the Effect of High Frequency Electromagnetic Fields, in Minecki, L., Bilski, R., Medical Reports (Selected Articles), FTD-TT-61-380, Foreign Technology Division, Wright-Patterson AFB, Ohio, Dec. 1961. (Translation of Medycyna Pracy, 12(4): 329-335).

1-39. Monayenkova, A. M., Sadchikova, M. N., Hemodynamic Indices During the Action of Super-High Frequency Electromagnetic Fields, LC-ATD-66-123, Library of Congress, Aerospace Technology Division, Washington, D. C., 1966. (Translation of Gigiyena Truda i Professional'nyye Zabolevaniya, 10(7): 13-21, 1966.

1-40. Murray, J. L., Some Biological Aspects of Microwave Radiation, (Master's Thesis), Department of Radiation Biology, The University of Rochester School of Medicine and Dentistry, Rochester, N. Y., 1963. (AD-415814).

1-41. Muth, E., Ueber die Erscheinung der Perlschnurketten-bildung von Emulsionspartikelchem unter Einwirkung eines Wechselfeldes, Kolloid-Zeitschrift, 41: 7-102, 1927.

1-42. Michaelson, S. M., Thomson, R. A. E., Howland, J. W., Comparative Studies on 1285 and 2800 Mc/sec Pulsed Microwaves, Aerospace Med., 36(11): 1059-1064, 1965.

1-43. Michaelson, S. M., Thomson, R. A. E., Quinlan, W. J., Jr., Effects of Electromagnetic Radiations on Physiologic Responses, Aerospace Med., 38(3):293-298, 1967.

1-44. Michaelson, S. M., Thomson, R. A. E., Odland, L. T., et al., The Influence of Microwaves on Ionizing Radiation Exposure, Aerospace Med., 34: 111-115, 1963.

1-45. Michaelson, S. M., Thomson, R. A. E., Howland, J. W., Physiologic Aspects of Microwave Irradiation of Mammals, Amer. J. Physiol., 201(2): 351-356, 1961.

1-46. Osipov, Yu. A., The Health of Workers Exposed to Radio-Frequency Radiation, in Gigiyena Truda i Vliyaniye na Rabotayuschikh Electromagnithykj Poley Radiochastot (Occupational Hygiene and the Effect of Radio-Frequency Electromagnetic Fields on Workers.) Med. Publ. House, Leningrad, 1965, pp. 104-144.

1-47. Osipov, Yu. A., Measures of Protection, Therapy, and Prophylaxis to be Taken During Work With Radio-Frequency Oscillators, JPRS-32735, Joint Publications Research Service, Washington, D. C., Nov. 1965. (Translation of Gigiyena Truda i Vliyaniye na Rabotayceshchikh Electromagnitnykh Bleg Radiochastot, 1965, Chapt. 8, pp. 156-202).

1-48. Osipov, Yu. A., Kalyada, T. V., Temperature Reaction of the Skin During Irradiation with Microwaves of Low Intensity, JPRS-23287, Joint Publications Research Service, Washington, D. C., Feb. 1964. (Translation of Gigiyena i Sanitariya, no. 10, 1963, pp. 73-78).

1-49. Overman, H. S., Quick Formulas for Radar Safe Distances, in Peyton, M. F., (ed.), Biological Effects on Microwave Radiation, Proceedings of the Fourth Annual Tri-Service Conference, Vol. I, Plenum Press, New York: 1961, pp. 47-54.

1-50. Pennock, B. E., The Measurement of the Complex Dielectric Constant of Protein Solutions at Ultra High Frequencies: Dielectric Properties of Hemoglobin Bound Water, (Doctoral Thesis) ONR-TR-41, Office of Naval Research, Washington, D. C., 1967. (University of Pennsylvania, Phila. Pa.)

1-51. Presman, A. S., Levitina, N. A., Influence of Non-Thermal Microwave Radiation on the Survivability of Gamma-Irradiated Animals, AEC-TR-5428, U. S. Atomic Energy Commission, Division of Technical Information, Washington, D. C. (Translation of Radiobiologiya, 2(1): 258-260, 1962).

1-52. Presman, A. S., Problems of the Mechanism of the Biological Effect of Microwaves, JPRS-22580, Joint Publications Research Service, Washington, D. C., Jan. 1964.

1-53. Richardson, A. W., Lomax, D. H., Nichols, J., et al., The Role of Energy, Pupillary Diameter, and Alloxan Diabetes in the Production of Ocular Damage by Microwave Irradiations, Amer. J. Ophthal., 35: 993-1000, 1952.

1-54. Rutkowski, A., Christianson, C., Development of RAD HAZ Suit and RF Measuring Techniques, NASL-9400-20-1, U. S. Naval Applied Science Laboratory, Naval Base, Brooklyn, N. Y., May 1965. (AD-463422).

1-55. Saito, M., Schwan, H. P., Schwarz, G., Response of Non-spherical Biological Particles to Alternating Electric Fields, Biophysical J., 6(3): 313-327, 1966.

1-56. Schaefer, H., Schwan, H., Zur Frage der Selektiven Erhitzung Kleiner Teilchen im Ultrakurzwellen-Kondensatorfeld, Annalen Physik, 43: 99-135, 1943.

1-57. Schaefer, H., Schwan, H., Zur Frage der Selektiven Uberhitzung von Einzelzellen im Biologischen, Strahlentherapie, 77: 123-30, 1947.

1-58. Schultz, F. V., Burgener, R. C., King, S., Measurement of the Radar Cross Section of a Man, Proc. IRE, 46: 476-481, Jan. - Apr. 1958.

1-59. Schwan, H. P., Piersol, G. M., Absorption of Electromagnetic Energy in Body Tissues: I. Biophysical Aspects, Am. J. Phys. Med., 33: 371-404, 1954.

1-60. Schwan, H. P., Absorption and Energy Transfer of Microwaves and Ultrasound in Tissues: Characteristics, in Glasser, O. (ed.), Medical Physics, Vol. 3, Year Book Publishers, Chicago: 1960, pp. 1-7.

1-61. Schwan, H. P., Biophysics of Diathermy, in Licht, S. H. (ed.), Therapeutic Heat, E. Licht, New Haven: 1958, pp. 55-115.

1-62. Schwan, H. P., Li, K., Capacity and Conductivity of Body Tissues at Ultrahigh Frequencies, Proc. IRE, 41: 1735-1740, Sept. - Dec. 1953.

1-63. Schwan, H. P., Carstensen, E. L., Li, K., Comparative Evaluation of Electromagnetic and Ultrasonic Diathermy, Arch. Phys. Med., 35: 13-19, 1954.

1-64. Schwan, H., Die Temperaturabhängigkeit der Dielektrizitätskonstante von Blut bei Niederfrequenz, Naturforschung, 3b: 361-367, 1948.

1-65. Schwan, H. P., Electrical Properties of Tissue and Cell Suspensions, in Lawrence, J. H., Tobias, C. (eds.), Advances in Biological and Medical Physics, Vol. 5. Academic Press, New York, 1957.

1-66. Schwan, H. P., Li, K., Hazards Due to Total Body Irradiation by Radar, Proc. IRE, 44: 1572-1581, Sept. - Dec. 1956.

1-67. Schwan, H. P., Survey of Microwave Absorption Characteristics of Body Tissues, in Pattishall, E. G., Banghart, F. W. (eds.), Biological Effects of Microwave Energy, Proceedings of the Second Tri-Service Conference, ARDC-TR-58-54, Rome Air Development Center, Griffiss AFB, N. Y., July 8-10, 1958, pp. 126-145. (AD-131477).

1-68. Seth, H. S., Michaelson, S. M., Microwave Cataractogenesis, J. Occup. Med., 7: 439-442, 1965.

1-69. Seth, H. S., Michaelson, S., Microwave Hazards Evaluation, Aerospace Med., 35(8): 734-739, 1964.

1-70. Sher, L. D., Schwan, H. P., Mechanical Effects of A. C. Fields on Particles Dispersed in a Liquid (Doctoral Thesis), Office of Naval Research, Washington, D. C., 1963. University of Pennsylvania, Philadelphia, Pa.

1-71. Shimkovich, I. S., Shilyaev, V. G., Cataract of Both Eyes Which Developed as a Result of Repeated Short Exposures to an Electromagnetic Field of High Density Vestn. Oftal., 72(4): 12-16, Jul. - Aug. 1959. (Abstracted in Lazarus, H. B., Levedahl, B. H., Effects of Radiation on the Mammalian Eye, A Literature Survey, TID-3912, DTIE-U. S. Atomic Energy Commission, Oak Ridge, Tenn., Nov. 1962, p. 447).

1-72. Smirnova, M. I., Sadchikova, M. N., Determination of the Functional Activity of the Thyroid Gland by Means of Radioactive Iodine in Workers Exposed with UHF Generators, in Letavet, A. A., Gordon, Z. V., (eds.), The Biological Action of Ultra-High-Frequencies, JPRS-12471, Joint Publications Research Service, Washington, D. C., Feb. 1962, pp. 47-49. (Translation of O Biologicheskom Vosdeystvii Sverkhyysokikh Chastot, Moscow, Acad. of Med. Sci., USSR, 1960. pp. 50-51).

1-73. Smurova, Ye. I., Rogovaya, T. Z., Yakub, I. L., Troitskiy, S. A., General Health of Persons Working with HF, UHF, and VHF Generators in Physiotherapy Machines. (Translation of Kazanskiy Meditsinskiy Zhurnal, no. 2: 82-84, 1966).

1-74. Susskind, C., and Staff, Nonthermal Effects of Microwave Radiation, RADC-TDR-62-624, Rome Air Development Center, Griffiss AFB, N. Y., Oct. 1962.

1-75. Thompson, W. D., Bourgeois, A. E., Effects of Microwave Exposure on Behavior and Related Phenomena, ARL-TR-65-20, 6571 Aeromedical Research Lab., Wright-Patterson AFB, Ohio. 1965.

1-76. Thomson, R. A. E., Michaelson, S. M., Howland, J. W., Microwave Modification of X-Ray Lethality in Mice, RADC-TDR-63-352, Rome Air Development Center, Griffiss AFB, N. Y., Aug. 1963.

1-77. Thomson, R. A. E., Michaelson, S. M., Howland, J. W., Microwave Radiation and Its Effect on Response to Ionizing Radiation (Abstract), Preprints of Scientific Program, Aerospace Medical Association, 37th Annual Meeting, Apr. 18-21, 1966, Las Vegas, Nevada.

1-78. Turner, J. J., The Effects of Radar on the Human Body (Results of Russian Studies on the Subject), Bell Telephone Labs.,Inc., Whippany, N. J., July 1962. (Summary based on Letavet, A. A., Gordon, Z. V., (eds.), The Biological Action of Ultra-High Frequencies, JPRS-12471, Joint Publications Research Service, Washington, D. C., Feb. 1962.)

1-79. U. S. Air Force, Electromagnetic Radiation Hazards, T. O. 31Z-10-4, Washington, D. C., Oct. 1961.

1-80. U. S. Army, U. S. Air Force, Control of Hazards to Health from Microwave Radiation, AFM-161-7, (TB-MED-270/AFM-161-7), Washington, D. C., Dec. 1965.

1-81. U. S. Navy, Washington, D. C., Safety Level of Electromagnetic Radiation with Respect to Personnel, USAS-95. 1-1966, USA Standard, 1966.

1-82. Williams, D. B., Monahan, J. P., Nicholson, W. J., et al., Biologic Effects Studies on Microwave Radiation: Time and Power Thresholds for the Production of Lens Opacities by 12.3 Cm Microwaves, SAM-55-94, School of Aviation Medicine, Randolph AFB, Texas, Aug. 1955.

1-83. Zaret, M. M, Ocular Effects of Microwave Radiation, Annual Progress Report, The Zaret Foundation, Inc., Scarsdale, New York, 1967. Grant No. DA-MD-49-193-67-G9224. (AD-654447).

1-84. Zaret, M. M., Opthalmic Hazards of Microwave and Laser Environments, Annual Progress Report, The Zaret Foundation, Inc., Scarsdale, New York, May 1967, Contract no. DA-49-193-MD-2592. (AD-654523).

1-85. Zaret, M. M., Cleary, S. F., Pasternack, B., et al., A Study of Lenticular Imperfections in the Eyes of a Sample of Microwave Workers and a Control Population, RADC-TDR-63-125, Rome Air Dev. Center, Griffiss AFB, N. Y., Mar. 15, 1963. (Discussions, pp. 61-71).